Proceedings of the American Academy of Arts and Sciences.

Vol. XLI. No. 10. — July, 1905.

THE RELATIVE POSITIONS OF THE ARC AND SPARK LINES OF THE SPECTRA OF TITANIUM, ZINC, AND IRON.

By Norton A. Kent.

With a Plate.

Investigations on Light and Heat made or published, wholly or in part, with Appropriations from the Rumford Fund.

THE RELATIVE POSITIONS OF THE ARC AND SPARK LINES OF THE SPECTRA OF TITANIUM, ZINC, AND IRON.

By Norton A. Kent.

Presented April 12, 1905. Received June 12, 1905.

Historical Survey and Statement of the Object of the Investigation.

In 1901 Haschek * stated that the lines of the spark spectrum of titanium exhibit considerable shift as compared with the same lines in the arc, a shift in one instance as great as 0.13 t.-m.

In 1903 the writer of the present paper made a careful experimental investigation of the subject.† No such large shifts were discovered; but it was shown that in all probability the wave-lengths of certain lines of the titanium spark spectrum are sensitive to various conditions of the electric circuit, such, for instance, as the amount of capacity, self-induction, and ohmic resistance employed, and the presence or absence of an auxiliary spark-gap in series with that under investigation.

The instrument used was a ten-foot Rowland grating. It seemed advisable to use greater dispersion. Hence the present work was undertaken with a twenty-one-foot grating. During its progress, Eder and Valenta ‡ (using a fifteen-foot instrument) have published a paper in which they state that neither in the case of pure zinc nor brass wire do the lines studied by Haschek show any shift. They attribute the results of these investigators to a photographic displacement of the centre of gravity of the lines due to over-exposure — the lines in question being those which exhibit very strongly the phenomenon of unsymmetrical broadening; and they suggest also the possibility of a pseudo-shift due to poor focus. The conclusion drawn by Eder and Valenta is that, at minimum photographic exposure, the coincidence of arc and spark line is perfect. Moreover, Middlekauff § has lately studied the iron spectrum

* Astrophysical Journal, **14**, 181 (1901).

† Ibid., **17**, 286 (1903).

‡ Ibid., **19**, 251 (1904).

§ Ibid., **21**, 116 (1905).

and finds no shifts in the region investigated. The focal length of his grating was twenty-one feet, six inches.

Such an inconsistency in the results of different investigators emphasizes the importance of taking extreme care in all the details of the experiment, guarding against any possible false shifts and stating with exactness all the conditions under which the investigation is made.

The objects of the present series of experiments are, then, to attempt to settle definitely the question of the coincidence or non-coincidence of arc and spark lines, to discover the determining conditions in case shifts do exist, and to harmonize, if possible, the results obtained by previous investigators.

Experimental Conditions; Construction and Adjustment of the Grating-Mount.

The conditions under which the present investigation has been carried out are as follows: The science hall of the college is a substantial building located not less than seventy-five yards from a roadway upon which there is heavy traffic; the foundations of the building are laid solidly upon glacial drift; and the room in which the spectroscope is mounted is situated in the cellar. The grating is a twenty-one-foot Rowland concave, of 15,000 lines to the inch, having a ruled surface of six by two and one-half inches. The grating holder is of brass, and is substantially built. The entire mount is of steel or iron. Seven-inch channel beams form two sides of the triangle, the third is a beam of five inches. The tracks are of two and three-fourths by one-half inch rolled steel. The carriages are massive; the truss-rod connecting the two is of $2\frac{1}{4}$-inch piping; and three draw-bars conduce to great rigidity. The camera box is of iron and brass, designed by the author, and is especially massive. The photographic plate is held in its place by brass screws. The slit is connected rigidly to the channel beams, and the whole mount is supported by rubber disks on three substantial brick piers. After adjusting the instrument for any definite region of the spectrum, the bases of the grating-holder and camera box were always clamped to the steel tracks by nine iron clamps of various sizes.

The camera shutter, being supported from the floor, is entirely free from the camera box, and is so arranged that there is absolutely no chance of mechanical jar from the operation of changing the shutter between exposures. The slit mechanism is surrounded by cardboard cylinders which are held free from the slit by supports connected rigidly to the walls of the room. Around these cylinders is tied the black cloth which

separates the dark spectrometer room from the light room in which are placed the spark and arc. The entire mount, including channel beams, steel tracks, trucks, truss-rod, draw-bars, and all possible parts of grating and camera box, is carefully wrapped in several layers of paper or cloth to facilitate obtaining constant temperature conditions. The steam pipes in the room are protected thoroughly by asbestos covering or several layers of paper.

In adjusting the instrument the slit and grating rulings were made parallel by the use of a plumb bob. The coincidence of the normals to the grating and to the plane of the camera box was determined by using an illuminated slit 1 mm. wide and adjusting until the image was horizontally coincident with the object. The ordinary method of superposing the image of a candle flame upon the flame itself was not regarded as sufficiently delicate.

Duration and Method of Exposure.

In general the exposures were short, ranging from three to ten minutes, and all the quantitative work of the investigation was carried

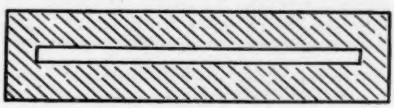

Figure A.

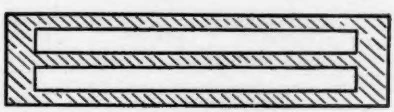

Figure B.

Figure C.

on when temperature conditions were most favorable, the change in temperature as given by one or more thermometers whose bulbs were placed underneath the cover of the mount usually being absolutely unreadable, and never more than a half of a tenth of a degree Centigrade. Moreover, the method of expose was such that pseudo-shifts, due either to mechanical jar or temperature change, must have been eliminated. The camera shutter was arranged as shown in the following cuts. Usually the arc was exposed first, its spectrum being placed along the centre of the photographic plate — this by use of the slit as given in Figure A; then the spark image was thrown upon the slit and its

spectrum placed on the edges of the plate — this by the use of the slits shown in Figure B; then the first operation was repeated, and the arc spectrum again thrown upon the centre. But in most cases, always during the latter part of the investigation, the shutter was so arranged that the vertical superposition of the first and third exposures was not perfect, so that the central portion of the plate containing the arc spectrum presents some such appearance as that shown in Figure C. A mechanical shift may thus be easily detected.

Production of the Sources of Light.

The spark was produced in the following manner: The city current (110 volts, 133 cycles per second) was led into a 5 kilowatt transformer (110 to 15,000, 30,000 or 60,000 volts) manufactured by the Central Laboratory Supply Co., of Lafayette, Indiana, in series with which was a home-made water rheostat. The secondary voltage ranged from approximately 1600 to 14,000 volts, as the ratio of transformation which was employed was 30,000 to 110. The high potential current was led into glass-paraffin-tin condensers giving a range of capacity varying from about 0.008 to 0.08 microfarads (see Table I). Both the charging and discharging high potential wires were very heavy (about No. 8 standard wire gauge).

TABLE I.

Capacity of Condensers.

No. of Condenser.	Approximate Area of one Element in cm^2.	Mean Thickness of Glass in cm.	No. of Elements.	Total Capacity in Microfarads.
1	900	0.245	4	0.0076
2	900	0.249	12	0.0226
3	900	0.241	10	0.0195
4	730	0.246	20	0.0315
5	730	0.479	8	0.0067

The self-induction coil employed consisted of three concentric cylindrical coils of dimensions given below (see Table II). Generally, when photographing the spark, there was placed in the rear of it, at a distance of 80 cm., a 12-inch Westinghouse fan, the strong air current from which was directed upon the spark-gap by a megaphone 70 cm. long, the smaller

opening (4 cm. in diameter) being about 2 cm. distant from the spark. When a secondary spark was used in series with that under investigation, the side draft from the fan was allowed to play upon it also. The fan undoubtedly produces greater disruptiveness and increases the potential of the discharge; but its steadying influence is very desirable, especially when self-induction is used in the discharge circuit. The luminous image was formed on the slit by a glass lens (aperture 3 inches, focal length 25 inches, made by Bausch & Lomb) situated about 110 cm. from the source of light and 152 cm. from the slit. This lens was held in a metal

TABLE II.

Dimensions of Self-Induction Coil in cm. Gauge Number of Wire = 14 s.w.g. External Diameter = 0.54. cm.

Coil.	Length.	External Diameter.	Total No. of Turns.
Inner	66.0	5.22	124
Central . . .	65.3	8.59	122
Outer	64.7	9.95	122

casing clamped to a marble slab which was set on an iron pipe imbedded in a cement foundation.

In all cases the spark which was being photographed was placed in a horizontal position in view of the possibility that different regions of the spark might show different spectra.

In the primary circuit of the transformer were placed a Thomson indicating watt-meter (maximum voltage 150 volts, maximum current 50 amperes, graduated in hectowatts) and a Thomson alternating ammeter (maximum current 100 amperes). The primary voltage was read by a Weston direct reading, alternating and direct current, voltmeter (two scale instrument, 15 and $7\frac{1}{2}$ volts, 1 to 10 multiplier).

The arc was developed by a 133 cycle alternating circuit, the current used being about 12 amperes, measured by a 50-ampere Aryton and Perry spring ammeter. The discharge took place between one-half inch carbons, the lower one of which was of the cored type and was hollowed out a trifle to receive the small pieces of metal used. The distance between the terminals was always in the neighborhood of 3 mm. That the energy for the spark and arc discharges could be obtained from the city circuit was a distinct advantage, for during the exposures there were

no mechanical vibrations due to heavy machinery, which would not have been the case if the current had been generated in the building.

Reduction of Astigmatism, Method of Measuring Plates, etc.

The investigation was confined to the second spectrum, the dispersion being one Ångström unit to 0.75 mm. The length of the rulings of the grating surface was diminished by reducing the vertical aperture to about 2 cm. (using black paper for the purpose); this process, together with stopping down the length of the slit to 5 or 6 mm., so much reduced the astigmatism that the tips of the spectral lines could be seen in the field of the micrometer used in measurement. We thus avoid a shift due to over-exposure, for, by setting the cross-hair upon the tip of the spark image, where it is just visible to the eye, we are certainly making use of minimum exposure conditions.

The filar micrometer (manufactured by Bausch & Lomb) was reinforced by adjustable trusses to produce greater rigidity.

A test of the accuracy of the instrument showed that the errors of measurement were greater than those of the screw. The magnification employed was about seven diameters, and a single cross-hair was found to give the best results. The plates were placed violet left, and four settings were made on the external or spark spectrum, then two upon the internal or arc spectrum; then the same set of measurements was repeated with the violet to the right. The plates used were the regular seed "Gilt Edge" 27, 5 × 7, cut into strips $1\frac{1}{4} \times 7$ inches.

The developer generally used was that described by Wallace * as giving with the seed 27 plate a definite and regular silver grain deposit.

Several plates were developed with Jewell's solution,† to which was

---

* Astrophysical Journal, **20**, 118 (1904). The formula was kindly sent the author by Mr. Wallace, and is as follows:

A.	Hydrochinon . . .	1 gm.	B. KBr . . .	1 gm.
	Metol	1 gm.	NaOH . .	12 gms.
	Adurol	2 gms.	H_2O . . .	175 gms.
	Na_2SO_3 (crystals) .	24 gms.		
	H_2O	175 gms.		

Take equal parts of A and B.

† A. Hydrochinon . .	30 gms.	B. Potas. ferro-cyanide .	30 gms.	C. K_2CO_3 30 gms.
Na_2SO_3 (crystals)	150 gms.	H_2O . . .	180 gms.	H_2O . 180 gms.
H_2O	750 gms.			
Alcohol	10 c.c.			

Take one part of B, one of C, and six of A. Normal amount of bromide, 15 drops (10 per cent solution) to 100 c.c. of developer.

added an excess of bromide (roughly 0.5 gram of potassium bromide to a 3 oz. solution).

Results.

The results are contained in the following tables, concerning the data given in which a few general remarks may be made: —

The time of the two arc exposures varied from 10 to 60 seconds, the short exposures predominating.

The length of the slit, unless otherwise stated, was either 5 or 6 mm., its width between 0.025 and 0.050 mm.

The arc spectrum was generally thrown on the centre of the plate.

The values of current, power, and voltage given in the tables are the means of from two to six (average three) readings taken at fairly regular intervals during the exposures. The conditions of the circuit were quite stable, the three elements seldom varying more than 1 ampere, 20 watts, and 0.3 volts respectively.

The metals used were: Titanium carbide or "cast titanium" (made by Eimer & Amend of New York), 85 per cent titanium, 15 per cent carbon; a titanium-iron alloy, 20 per cent titanium, 80 per cent iron (Eimer & Amend); zinc battery rods; brass wire, 30.2 per cent zinc, 69.8 per cent copper; ordinary iron rod.

Unless otherwise stated the part of the spark image used was that near one terminal and the fan was employed to steady the discharge.

The secondary spark took place between brass rods 4 mm. in diameter.

The focus, to an accuracy of 1 mm., was determined repeatedly from week to week as the temperature of the room changed. This was a precautionary measure: no change in focus was noticed.

The given values of the shifts represent generally but one set of measurements on each plate, never more than two. This course was pursued because the different plates agreed so well that numerous measurements upon the same plate were deemed unnecessary. The average deviation from the mean of the measurements on the different plates in all the sets was about 0.0027 tenth-meters for titanium and iron, and 0.0070 for zinc. The average deviation from the mean of different measurements of a line on any one plate was about 0.0025 tenth-meters for titanium, 0.0018 for iron, and 0.0060 for zinc.

To gain in another manner an idea of the degree of accuracy of measurement, four settings, two red-right and two red-left, were made *

* A suggestion due to Professor Frost.

on each of three lines: Ti, λλ 3898.645, 3901.114, and 3904.926 (Rowland's table of solar wave-lengths), as they appeared on a focus plate. The first line only was reversed: all were somewhat too dense for very accurate settings. Assuming the values of the wave-lengths of the first and third lines as given, that of the second was calculated. The first determination gave 3901.112, the second 3901.114; the mean 3901.113, but 0.001 tenth-meter different from the wave-length as given above.

Unless otherwise stated the developer used was the Wallace solution.

The spark lines which were studied most thoroughly, namely Ti, λλ 3900 and 3913; Zn, λλ 4680, 4722, and 4810, generally appear enhanced, diffuse, and unsymmetrically broadened. Many iron lines also show unsymmetrical broadening to some extent.

Figures 1, 2, and 3 of the accompanying plate are illustrative of the lines studied. The scratches, appearing at the tips of the spark and between the arc and spark segments, were drawn by pricking two holes in the film of a positive of the original negative at points which seemed to lie in the "centre of gravity" of the very tips of the spark lines. These two points were then joined by a ruler and the film carefully scratched away along its edge in the four regions above mentioned. A negative of the positive was then made. From the three negatives prepared in this manner the positive reproductions were developed.

The arc line lies considerably to the left, or violet, in all cases but that of Figure 2, which is a "self-induction line." It will be noticed that the double arc exposure as sketched in Figure C appears only in Figure 3 of the plate. As stated previously, this non-superposition method was not used at the very first of the investigation.

The scale of the enlargements is about five to one.

Let us discuss first the results as given by the titanium plates in Table III: —

1. The members of the set of six plates, set 1 (see next to last column of the table), agree in showing that with large capacity shifts exist (about 0.023 t.-m.), even in the absence of a secondary gap.

2. Set 2 (5 plates) shows that, with a secondary gap of 4 mm. and lessened capacity, considerable shifts exist (about 0.037 t.-m.). The effect of a secondary gap is to increase the potential of the discharge, and this gives the same result as an increase of capacity.

3. A condition (set 3) given by an increase of secondary gap and further reduction of capacity still presents a shift (about 0.033 t.-m.). It may also be seen that plates Nos. 8, 16, and 25 (sets 1, 2, and 3), on which the arc spectrum was photographed outside of the spark spectrum,

show no marked or consistent difference from those obtained in the ordinary manner. Care was taken that the spark exposure be very short.

4. Introducing the self-induction coil into the discharge circuit of the condenser (set 4) unquestionably conduces to coincidence of arc and spark line (mean value of shift 0.005 t.-m.).

5. Sets 5 and 6 show that the use of the alloy, 20 per cent titanium, 80 per cent iron, give much less displacement (0.002 t.-m.) than that given by titanium carbide, 85 per cent titanium, 15 per cent carbon (about 0.02 t.-m.).

6. The part of the spark image used is extremely important; set 7, given by that region of the image near the terminal, shows a shift of 0.018 t.-m., while the central portion of the spark (set 8) 4.5 mm. from the terminal shows but about 0.006 t.-m.

7. Sets 9 and 10 show that ohmic resistance (2.7 ohms) in the discharge circuit of the condenser produces an effect exactly similar to that of self-induction (see result No. 4), reducing the shift from about 0.017 t.-m. to practically zero.

8. Sets 7 to 10, in which no fan was used, show that the same is not a *sine qua non* in the matter of shift.

9. Further, the developer used appears to have no effect upon the shift. Therefore in sets 5, 7, 8, and 10 the measurements made on plates developed with the Jewell solution are averaged in with the others. Indeed it is difficult to see how there could be a difference, provided the tip of the line be used in measurement. If, however, the setting be made upon the body of the line a difference might very easily be introduced (see below, result No. 16), a "softer" developer, such as Wallace's, tending to displace the apparent centre of gravity of the line toward the side of greater broadening.

10. Sets 11 and 12, also 11 and 13, Table IV, show that the alloy and self-induction effects of sets 6 and 7, also 3 and 4, Table III, respectively, hold good with lines of the spectrum other than $\lambda\lambda$ 3900 and 3913.

11. Set 14 shows that large shifts exist in lines in other regions, e. g., λ 4827.74, 0.024 t.-m.; λ 4836.25, 0.036 t.-m.

It is also noticeable that whenever both spark and arc lines are reversed the central portions of the reversal are coincident.

Passing to zinc, Table V, we have:

12. Sets 15, 16, and 17 give results comparable with those of 3, 1, and 2 for titanium, and sets 18 and 19 confirm the alloy effect of 6 and 7 and also 11 and 12.

TABLE III.

SHIFT OF SPARK LINE TOWARD RED IN

No. of Plate.	Date.	Length of Spark Exposure in Min.	Constants of Electric Circuit.							Character of Lines. S = Sharp. D = Diffuse.
			Primary.			Secondary.				
			Amps.	Watts.	Volts.	Capacity in Micro-farads.	Lgth. of Gap in mm. Prim'y.	Lgth. of Gap in mm. Secondary.	Part of Image used.	
6	Dec. 15	15	40.6	193	6.8	0.0812				
7	" "	15	41.1	180	7.0	0.0812				
8	" 16	15	40.4	188	6.5	0.0812	1.0	0	End	D
9	" "	22	40.9	172	5.8	0.0812				
10	" 17	26	39.7	188	6.3	0.0812				
28	" "	15	40.0	160	7.2	0.0803				
12			39.0	390	12.0		1.5			
13			37.8	390	12.5		2.0			
14	" "	5	38.3	400	13.0	0.0195	1.7	4.0	End	D
15			38.5	380	11.3		2.1			
16			38.5	380	12.2		2.5			
22	Jan. 14	6	35.5	1010	46.0		2.0	31		
23	" 17	5	34.1	910	37.0	0.0067	1.0	27	End	D
24	" "	6	34.4	910	36.0		2.0	27		
25	" "	5	34.0	883	38.3		2.0	27		
26	" "	5	35.0	717	35.0	0.0067	2.0	27	End	S
27	" 21	7	33.6	775	41.0			25		
70	April 15	5	41.5	415	11.6					
72	" "	3	42.4	400	11 3	0.0226	2.0	5	End	D
93	May 5	8	41.4	395	10.9					
99	" "	11	41.2	400	11.2					
77	April 15	5	41.7	397	11.1	0.0226	2.0	5	End	S
78	" "	9	41.2	420	11.3					
73	" "	4	41.5	440	12.0					
74	" "	3	41.1	410	11.5					
97	May 6	9	39.8	417	11.2	0.0226	9.0	0	End	D
101	" "	10	41.2	410	11.5					
102	" "	10	41.0	427	11.5					
75	April 15	4	41.6	425	11.7					
76	" "	3	41.5	435	11.5	0.0226	9.0	0	Centre	D
96	May 5	6	41.5	425	11.4					
98	" 6	9	41.0	425	11.1					
80	April 29	10	41.3	297	9.1					
81	" "	15	41.9	313	9.0	0.0226	4.0	0	End	S
82	" "	15	41.9	313	9.0					
83	" "	5	42.1	320	8.9					
84	" "	4	41.5	315	9.0					
87	May 2	8	41.8	300	9.2					
88	" "	7	42.0	300	9.1	0.0226	4.0	0	End	D
103	" 10	10	40.7	307	8.7					
104	" "	10	40.2	300	8.5					
105	" "	8	40.9	315	8.6					
106	" "	8	41.3	310	8.4					

TITANIUM.

TENTH-METERS: POSITIVE UNLESS OTHERWISE STATED.

Metal used.	Fan.	Shift. λ 3900.68. Separate Measurements.	Shift. λ 3900.68. Mean.	Shift. λ 3913.58. Separate Measurements.	Shift. λ 3913.58. Mean.	No. of Set.	Remarks.
85 % Ti 15 % C	Yes	0.036* 25 21 18* 21 18	*0.023*	0.031 24 20 22 24 22	*0.024*	1	Plate No. 8, spark inside; arc outside.
85 % Ti 15 % C	Yes	0.042 35 38 37 39	*0.038*	0.048 30 39 31 34	*0.036*	2	Plate No. 16, spark inside; arc outside.
85 % Ti 15 % C	Yes	0.045 36 26 32	*0.035*	0.041 25 28 30	*0.031*	3	Plate No. 25, spark inside; arc outside.
85 % Ti 15 % C	Yes	0.002 8	*0.005*	0.004 7	*0.005*	4	Triple coil of self-induction used.
85 % Ti 15 % C	Yes	0.027* 15* 21 17	*0.020*	0.026* 23 16* 24	*0.022*	5	Developed with Jewell solution.
20 % Ti 80 % Fe	Yes	0.001 4	*0.002*	0.003	*0.003*	6	
85 % Ti 15 % C	No	0.020 14* 22 21 17	*0.019*	0.017* 17* 19 23 15	*0.018*	7	Developed with Jewell solution.
85 % Ti 15 % C	No	0.006 6 6 7	*0.006*	0.003 6 5 7	*0.005*	8	Developed with Jewell solution.
85 % Ti 15 % C	No	−0.001 −7 10	*0.001*	−0.001 −6 3	*−0.001*	9	Two meters of fine wire resistance 2.7 ohms, in discharge circuit of condenser.
85 % Ti 15 % C	No	0.020* 18* 16* 14* 13 20 18 14	*0.017*	0.023* 18* 12* 15* 15 20 17 17	*0.017*	10	Developed with Jewell solution.

* Mean of two measurements.

TABLE IV.

SHIFT OF SPARK LINE TOWARD RED IN TENTH-
END OF IMAGE NEAR TERMINAL SET UPON SLIT;

Number of Plate.	Date.	Length of Spark Exposure in Minutes.	Constants of Electric Circuit. Primary. Amps.	Primary. Watts.	Primary. Volts.	Secondary. Capacity in mf.	Secondary. Gap-Length in mm. Pri	Secondary. Gap-Length in mm. Sec.	Shift and Character of (b = bright line. r = reversed line.) λ 4443.97 A b / S b	λ 4443.97 Mean.	λ 4468.65 A b / S b	λ 4468.65 Mean.	λ 4489.24 A b / S b	λ 4489.24 Mean.
57	Mar. 18	5	40.4	433	11.9	0.0226	2	5	—0.005*	*—0.002*	0.009	*0.008*	0.008	*0.008*
60	"	5	40.8	398	11.1				2		8*		8	
63	Apr. 8	10	41.9	403	11.3	"	"	"	0.003	*0.003*	—0.001	*0.002*		
64	"	12	41.8	373	11.1				. .		5			
59	Mar. 18	5	41.2	357	12.1	"	"	"	*—0.001**		*0.003*		*—0.001*	

Number of Plate.	Date.	Length of Spark Exposure in Minutes.	Amps.	Watts.	Volts.	Capacity in mf.	Pri	Sec.	λ 3223.1 † A r	λ 3223.1 † S r	λ 3228.0 † A b	λ 3228.0 † S b	λ 3235.0 † A r	λ 3235.0 † S r
49	Mar. 13	12	40.6	450	12.0	0.0226	2	5	*—0.001*		*0.002*		*0.001*	

* Mean of two measurements.
† Third order spectrum. Wave-lengths given approximately.

TITANIUM.

METRES; POSITIVE UNLESS OTHERWISE STATED.

METAL 85% Ti, 15% C, UNLESS OTHERWISE STATED.

ARC AND SPARK LINES.
A = arc line. S = spark line.

λ 4533.42 A r / S b	Mean.	λ 4534.15 A b / S b	Mean.	λ 4549.79 A b / S b	Mean.	λ 4563.94 A b / S b	Mean.	λ 4572.15 A b / S b	Mean.		No. of Set.	Remarks.
0.013 . .	*0.013*	0.010 4	*0.007*	0.022 18	*0.020*	0.003 4	*0.003*	0.016 25	*0.020*		11	
		—0.007 . .	—0.007	0.006 5	*0.005*			0.001 2	*0.001*		12	20% Ti, 80% Fe.
—0.006 ‡		*0.001*		*—0.001*		*0.001*		*—0.003*			13	Triple coil of self-induction used.

λ 3237.5 †		λ 4827.74		λ 4836.25		λ 4844.13		λ 4848.62		λ 4856.18		No. of Set.	Remarks.
A	S	A	S	A	S	A	S	A	S	A	S		
r	r	b	b	b	b	b	b	b	b	b	b		
0.000		*0.024*		*0.036*		*0.015*		*0.015*		*—0.005*		14	

‡ Spark line on this plate is reversed.

TABLE V.

SHIFT OF SPARK LINE

No. of Plate.	Date.	Length of Spark Exposure in Minutes.	Constants of Electric Circuit.								Metal Used.
			Primary.			Secondary.					
			Amps.	Watts.	Volts.	Capacity in Micro-farads.	Length of Gap in mm. Pri.	Length of Gap in mm. Sec.	Part of Image used.	Shape of Terminals.	
31	Jan 27	10	33.4	955	36.0		?	25			
33	Jan. 28	10	32.5	946	38.8		2	24			
34	Jan. 28	15	32.8	965	41.0	0.0067	2	21	End	Flat 3 × 6 mm.	Zn battery rods.
36	Feb. 3	15	34.8	983	41.0		2	21			
37	Feb. 3	15	33.2	998	42.5		2	21			
38	Feb. 3	30	41.1	198	7.4	0.0736	1	0	End	"	"
41	Mar. 4	4	41.0	440	12.8	0.0195	1.5	3	End	Round 3 mm. diameter	"
42	Mar. 4	6	40.8	445	13.2						
45	Mar. 11	20	41.2	343	9.6	0.0226	2	2.5	End	" Flat 1 × 3 mm.	30.2% Zn 69.8% Cu
46	Mar. 11	18	41.7	350	9.7						
47	Mar. 11	10	40.7	490	14.2			2	End		
48	Mar. 11	10	40.8	463	13.8	0.0226	2	2		"	Zn battery rods.
43	Mar. 4	5	42.0	385	11.1			2.5			

ZINC.

TOWARD RED IN TENTH-METERS.

Fan.	Shift.						No. of Set.	Remarks.
	λ 4680.38.		λ 4722.26.		λ 4810.71.			
	Separate Measurements.	Mean.	Separate Measurements.	Mean.	Separate Measurements	Mean.		
	. .		0.066		0.048			
	0.019		43		30			
Yes	37	*0.028*	40	*0.042*	30	*0.039*	15	
	24		36		48			
	32		26		. .			
"		*0.025*		*0.047*		*0.039*	16	
"	0.034	*0.033*	0.047	*0.047*	0.071	*0.065*	17	
	33		48		59			
"	0.003	*0.003*	0.000	*0.003*	0.017	*0.012*	18	Filings from zinc battery rod used in arc as in other cases. Lines sharp.
	. .		6		8			
	0.029*		0.059*		0.084*			Plate No. 48 developed with Jewell solution and normal amount of bromide.
"	. .	*0.032*	63	*0.065*	125	*0.102*	19	
	35		74		97			

* Mean of two measurements.

13. In iron, Table VI, we find that, among the lines investigated, the shifts are in general very small, but are nevertheless present.

Further facts are as follows:

14. A plate on which three exposures were made in the usual manner, the first and third being superposed, and the source of light being the titanium arc, shows that no shift is introduced by throwing a diffuse image on the slit, destroying the focus by moving the arc two inches nearer the

TABLE VI. Iron.*

Shift of Spark line toward Red in Tenth-meters.

Wave-length.	Shift.	Wave-length.	Shift.
3688.58	0.004	3788.01	0.001
3705.10	2	95.13	3
9.37	3	99.68	3
20.07	3	3815.97	10
27.78	3	27.96	6
48.39	5	34.37	7
58.36	5	40.58	2
63.93	6	41.19	8
67.34	5		

lens. This proves that even if either arc or spark were out of focus to a small extent the shift would not be altered.

15. A plate exposed to the carbon and graphite arcs shows that no shift occurs between lines which are due to the same impurities in both. The currents used were 33 and 75 amperes respectively. The graphite arc is produced with considerable difficulty, a large current being required,

* The conditions under which the iron plates were obtained are as follows: Six plates taken at various times; average spark exposure, 12 minutes; average current, power, and voltage, 41.3 amperes, 420 watts, 11.5 volts; capacity, 0.0226 microfarads; length of primary gap, 9 mm.; no secondary gap and no fan; region of spark image used, that near terminal. The above values of the shift are means of measurements made on from two to six plates.

and the discharge is quite explosive. It was thought that this explosive effect might produce a small shift toward the red.* Evidently the disruptive effect is of too great a period and not sufficiently violent.

16. A plate was taken under conditions similar to those of Nos. 83 and 84, except that the slit-length was extended to about 1 cm., the whole vertical aperture of the grating was used, and the exposure lengthened to ten minutes. Under these conditions there results a greatly over-exposed spark spectrum. Upon careful measurement, setting on what appears to be the maximum of intensity of the body of the line, shifts as great as 0.031 and 0.025 t.-m. appear; whereas set 10 gives values of 0.017 and 0.017. It is evident, then, as Eder and Valenta suggest, that by over-exposure a false displacement may be introduced in a line marked by unsymmetrical broadening.

TABLE VII. Titanium.

Data transferred from Table III.

Mean Current in Amperes.	Mean Power in Watts.	Mean Potential Difference in Volts.	Mean Shifts for λλ 3900, 3913.	Set.	Effect of
40 5	180	6.6	0.023	1	
38.4	388	12.5	37	2	
34.5	928	39.3	33	3	self-induction.
34.3	746	38.0	5	4	
41.6	402	11.3	21	5	alloy.
41.5	409	11.2	2	6	
40.9	421	11.5	18	7	part of spark image.
41.4	428	11.4	5	8	
41.7	308	9.0	0	9	ohmic resistance.
41.3	308	8.8	17	10	

17. By referring to Table VII, the data given in which are taken from Table III, it will be seen that the energy involved is not the only

* The suggestion that a comparison of these two spectra be made is due to Professor Crew.

element in the shift, for sets 3 and 4, in which nearly the same power (928 and 746 watts) was used show a large difference in shift. This is due to self-induction, which causes less disruptiveness in the discharge.

Ohmic resistance (sets 9 and 10) gives the same effect.

The influence of a low percentage alloy appears in sets 5 and 6, and the difference between the centre and end regions of the spark is shown in sets 7 and 8.

It may be remarked that set 3 (power 928 watts) shows less shift, 0.033, than set 2 (power 388 watts), 0.037; but the difference is very small, and moreover the disruptiveness in the latter case may have been greater.

Summation of Results.

In conclusion it may be said that the writer's former results have been qualitatively and, to a certain degree, quantitatively confirmed. It is difficult to see how we can avoid the following deduction: Under certain conditions, namely, when self-induction and ohmic resistance are absent, large capacity or long secondary gap are used, and the terminals are of a high percentage alloy, the part of the spark which lies near the terminal gives a spectrum, the wave-lengths of the lines of which are greater than those of the arc spectrum. The shifts occur when the energy involved in each discharge is great, and the discharge is disruptive in nature. These conditions mean the creation of a large amount of metallic vapor in a short time — a highly explosive phenomenon. That an increase of wave-length should result is rather to be expected. This may be rendered more evident from the following discussion:

In addition to those theoretical considerations (mentioned in the writer's former paper) * which would lead us to expect an increase in wave-length, namely those dealing with the pressure, "p," in a gaseous medium as a function of the number of particles per c.c., "n," the mass of each, "m," and the mean squared velocity, "u^2," postulating the truth of the equation $p = \frac{1}{3} m n u^2$, it may be stated that such an increase in pressure may come from the fact that, at the beginning of the discharge, the air acts as an incompressible medium (compare the downward explosive effect of dynamite placed on the surface of the earth). The development of the metallic vapor takes place so quickly that the air has no time to move. The lessened shift in the centre of the spark can then be easily explained, for it is known that some time

* Astrophysical Journal, **17**, 296 (1903).

elapses before the metallic particles, advancing from the terminal, reach the central region of the spark. When they have finally reached this region the air has yielded and the pressure fallen. An unusual amount of vapor is disengaged in the discharge between electrodes of titanium and zinc in water (not so prominently the case with iron). That the pressure developed is also great was noticed by the writer in his work with Professor Hale on the spark under water.* The terminals were badly shattered; indeed there is good reason to expect that the lines of the spectrum given by the discharge in air pass through a series of changes which resembles that in water. Certain titanium lines appear reversed on some of the present series of plates and not so on others. The reversal comes up unsymmetrically on the violet edge of the centre of gravity of the line, a common occurrence in the spectra of the spark under water. The question of the exact parallelism of the two phenomena must be reserved for future investigation.

Possible Explanation of the Inconsistent Results of Haschek, Eder and Valenta, and Middlekauff.

Haschek undoubtedly dealt with over-exposed lines and increased the true shift by a photographic displacement of the region of maximum intensity.

Eder and Valenta probably used a vertical spark and set the central region of the same on the slit of the spectrometer (the lines studied by the writer, Zn $\lambda\lambda$ 4680, 4722, and 4810, are among those investigated by Eder and Valenta). We are assuming that the same effect obtains in the case of zinc as with titanium (sets 7 and 8, deduction No. 6 above) with reference to the central and end portions of the spark. That no shift exists under the conditions employed between the absorption regions of reversed arc and spark lines, as stated by Eder and Valenta for zinc, was found to be true in the case of titanium.

Lastly, that Middlekauff found no shift with iron may easily be explained by the fact that few lines show a shift, and these generally to but a small degree, under highly disruptive conditions and near the region of the terminal. Middlekauff probably used a comparatively weak spark, set its image vertically on the slit, and integrated with his spectrometer the spectra of the central regions.† Moreover Middlekauff and

* Astrophysical Journal, **17**, 154 (1903).

† The statement is made that the spark was eight or nine mm. in length and its image on the slit about 6 mm.

Eder and Valenta may have used small wires in the discharge circuit of the condenser and so have introduced ohmic resistance.

Influence of Results upon the Mapping of Spark Spectra and upon Stellar Line of Sight Work.

The bearing of the above results upon radial velocity investigations in which a titanium spark is employed to give the comparison spectrum is such as to emphasize the fact that low-energy and non-disruptive conditions should be employed if the lines of the resultant spectra are assumed to be severally of the same wave-length as those of the arc or the absorption and bright lines of the stars. Furthermore, if a highly disruptive spark be used, the same circuit conditions should be employed at all times in any one observatory, to make the plates there taken mutually comparable; or, finally, the same conditions should prevail at all observatories if mutually consistent results are desired.

The general bearing upon the mapping of spark spectra may be seen in the fact that an agreement between the wave-lengths of spark lines as measured by various investigators is impossible unless the conditions of the electric circuit be the same in all cases.

In conclusion, I wish to acknowledge my indebtedness to the Rumford Committee for the two grants which made this work possible, and to Professors Hale and Frost of the Yerkes Observatory for the loan of the grating used. I am also under obligation to Dr. George S. Isham for the gift of the filar micrometer, and to Mr. Cornelius Vanderbilt for generous financial aid. My assistants, Messrs. Hartley and Miller, have proved invaluable at various times; and to Mr. Boord I am indebted for the analysis of the brass wire.

Wabash College, Crawfordsville, Indiana,
June, 1905.

EXPLANATION OF PLATE.

Figure 1.

Positive of Ti λ 3913.58 as apparent on plate No. 22.
Mean shift as given by plates 22 to 25, 0.031 t.-m.

Figure 2.

Positive of Ti λ 3913.58 as apparent on plate No. 27.
Influence of self-induction shown.
Mean shift as given by plates 26 and 27, 0.005 t.-m.

Figure 3.

Positive of Zn λ 4722.26 as apparent on plate No. 47.
Mean shift as given by plates 47, 48, and 43, 0.065 t.-m.

FIG. 1.

FIG. 2.

FIG 3.